Application of Remote Sensing Technology in the SA Sugar Industry

Review of Recent Research Findings

E J SCHMIDT*, G NARCISO**, P FROST**, C GERS*

* *SA Sugar Association Experiment Station* ** *ARC Institute of Soil Climate and Water*

Abstract

Remote sensing broadly refers to measuring reflected electromagnetic energy using a camera or sensor. The application of this technology in agriculture makes use of a wide range of instruments ranging from aerial cameras to sensors mounted on orbiting satellites.

The ARC Institute of Soil, Climate and Water recently completed two projects that were contracted by SASEX. These projects investigate the use of remote sensing for monitoring sugarcane condition and yield estimation. These studies investigated:

1. The use of a Digital Multi-Spectral Video camera (DMSV), mounted on a microlite, for crop monitoring.
2. The use of the National Oceanographic and Atmospheric Administration (NOAA), Advanced Very High Resolution Radiometer (AVHRR) for yield estimation on a regional scale.

This paper reviews the major research findings of these projects and identifies further operational challenges for commercial use of remote sensing in sugarcane production.

Introduction

Remote sensing allows information to be obtained for a target crop by measuring the intensity of reflected electromagnetic energy. By assessing the reflectance of various wavelengths within the electromagnetic spectrum, a "spectral signature" for the crop can be established. The signature will depend on the characteristics and condition of the crop. Image processing software can be used to identify the combination of bands that best identify a particular characteristic of the crop. The resulting digital image of the crop surface is made up of a large number of pixels, each representing a parcel of land.

Both digital airborne cameras and orbiting satellite sensors can be used to measure reflected energy from the crop canopy. The choice of sensor, its filters and carrying platform will dictate the ground resolution of each pixel and the wavebands of electromagnetic energy measured. The frequency of image acquisition and cost of data will also influence the choice of sensor most suitable for agricultural operations. Giovani and Schmidt (1999) have reviewed some of the satellite systems commonly used for remote sensing projects in agriculture.

Two important areas where remote sensing can potentially play a role in the sugar industry is in monitoring crop condition and estimating crop size. Timeous information on crop condition would allow management intervention to improve production and profitability. Such farm management decisions could cover irrigation scheduling, application rates and timing for fertiliser and ripeners, weed control, as well as implementation of drainage and pest and disease control measures. Estimates of crop size using remote sensing, would assist in crop marketing and pricing strategies, mill operating decisions and scheduling crop harvesting and haulage operations.

The ARC Institute of Soil Climate and Water, recently completed two projects investigating the use of remote sensing for sugarcane monitoring, crop condition assessment and yield estimation. These studies investigated the use of a Digital Multi-Spectral Video camera (DMSV), mounted on a microlite, for crop monitoring (ARC, 2000a) and the use of NOAA AVHRR satellite data for sugarcane yield estimation on a macro scale (ARC, 2000b). An assessment of research methodology and findings from these projects is given below.

DMSV Multi-spectral video camera

Methodology

A fixed-wing microlite and four channel Digital Multi-Spectral Video camera (DMSV) was used to acquire images of the Pongola research farm and two nearby commercial farms, during April and May 1999. The investigation aimed to evaluate the operational benefits of this technology for the sugar industry.

Airborne sensors have been widely used in agriculture to measure the intensity of reflected electromagnetic energy in various wavelengths and in so doing to obtain a "spectral signature" of the crop surface. A comprehensive bibliography is given in ARC (2000a). The amount and wavelength of light reflected in different wavelengths is determined by the characteristics of the crop (Guyat, 1990). Typically reflectance in the 400 to 450nm range is related to chlorophyll, while reflectance in the near infrared portion of the spectrum is a direct function of moisture content in the foliage. By integrating the reflectance of various wavelengths into a vegetation index, a characteristic of the crop surface can often be identified which is not visible to the eye.

The DMSV sensor system used comprises four wavebands of wavelength 450nm, 550nm, 650nm and 750nm (Figure 1). The sensor was mounted on a fixed-wing microlite with a GPS system for rapid image geo-referencing and mosaiking (Figure 2). The DMSV sensor has a ground resolution of between 0,5m and 3m, depending on flying height. In this study a 0,5m resolution was adopted. Various image processing techniques including band selection, classification and principal component analysis were explored to best explain features measured in the field (ARC, 2000a).

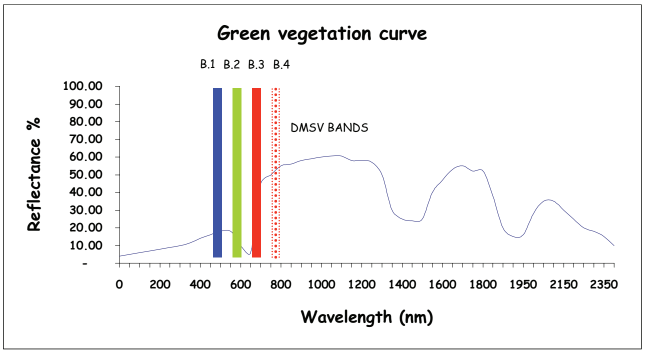

Figure 1. DMSV Bands relative to the generic green vegetation curve (ARC, 2000a).

Figure 2. The "Jabiru" microlite platform and DMSV sensor.

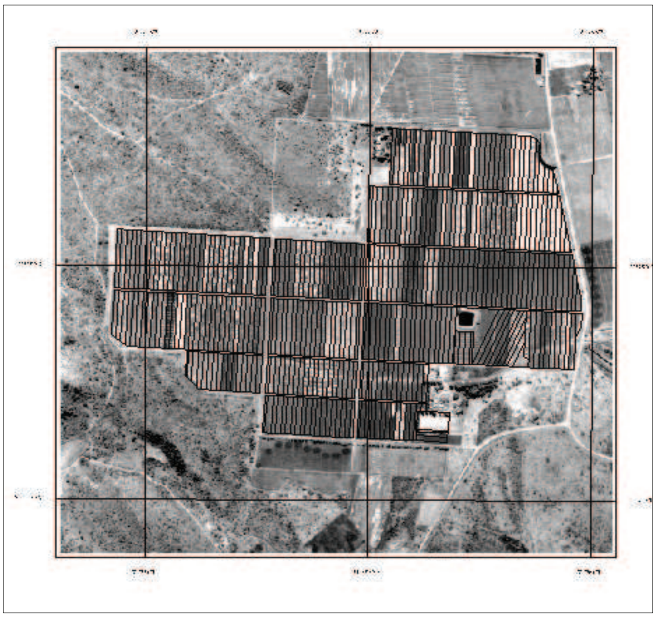

Figure 3. Map layout of the Pongola research farm.

Standard vegetation indices, comprising combinations of the four wavebands were used to provide an index of vegetation reflectance. These included the RVI (ratio vegetation index), and TNDVI (transformed normalized difference vegetation index) (Wiegand, Richardson, Escobar and Gerbermann, 1991). Figure 3 gives a layout map composition of the Pongola research farm.

A number of trials were set up on the Pongola research farm to assess the ability of DMSV to identify various field and crop conditions. Issues investigated included:

- Crop moisture stress
- Surface conditions of bare soil plots
- Sugarcane variety
- Age of crop and stage of development
- Crop response to ripening
- Nutrition status of the crop
- Field production potential and yield at harvest

Field and laboratory measurements were incorporated into a database for comparison with the spectral signature of each plot, as measured with the DMSV camera. Measurements included, soil moisture status, sugarcane green leaf count and sucrose content, variety identification, crop age and ground cover status as well as NIR spectroscopy analysis of soil and leaf samples.

A summary of the main findings is given below.

Results

a) Crop moisture stress

Two experiments were set up to assess whether DMSV could distinguish different levels of moisture stress (dry, moist and wet soil conditions). The results of one experiment could not be meaningfully used due to poor control of water distribution using the overhead irrigation system as well as a corrupted DMSV image. The results of the second experiment from drip irrigated plots indicated a significant correlation between canopy reflectance (RVI and TNDVI) and soil moisture at 100cm depth. Correlation reduced at shallower depths. Changes in soil moisture between plots were not strongly evident in measured green leaf count, suggesting that crop response to changes in soil water were not well developed in the sugarcane. The results indicated that the DMSV sensor has potential to identify, from sugarcane canopy, different levels of moisture stress at an early stage of development. Controlled experiments on areas of poor drainage did not form part of this project. Nevertheless, cursory viewing of the DMSV image gives a clear indication of areas known to have drainage problems.

b) Bare soil analysis

Strips were rotavated in two fields, of differing soil properties, a week before and just prior to image acquisition. The purpose of the experiment was to investigate the relationship between reflectance measured by DMSV, and soil surface conditions. Surface soil samples were taken at intervals along each strip to determine moisture content, clay percentage and NIR reflectance of soil samples. There were significant but inconsistent relationships between reflectance, measured in the various wavebands, and field measurements.

Multi-spectral remote sensing for classifying soil and recognition of soil patterns has been widely demonstrated in the literature and differences in soil characteristics were evident from a simple visual analysis of the images acquired. No quantitative determination of soil features was however possible from this study.

c) Variety identification

The scope of this experiment was to verify the capability of DMSV to discriminate spectrally between varieties. The experiment was set up over three fields and twenty- four plots, each with a different variety. The results showed that while each variety had its own spectral signature there was marked variability within a variety, owing to border effects (eg shading of plots), lodging and within plot variation of moisture stress (due to non uniform water application with sprinklers).

Principal component analysis was used to remove "noise" in the data and showed that it is possible to identify a specific variety and discriminate it from another. Figure 4 gives a bubble diagram based on the principle component analysis of the varieties. The operational usefulness of this procedure needs to be further investigated to check that a spectral signature is stable in time (age of crop) and space (topographical position and crop condition).

Variety identification would be useful for the identification of non-certified varieties and monitoring adoption of new varieties relative to production areas or topographical position. Consideration could be given to genetic marking of sugarcane to give a clear spectral response in a selected waveband.

d) Ripener application

Routine ripening experiments are conducted at Pongola research farm by the SASEX Agronomy department. Plots were targeted that had been ripened with Ethrel (between 3 and 8 weeks prior to flight date) and with Fusilade (between 5 and 14 weeks prior to flight date). Canopy reflectance in each of the 4 DMSV wavebands was assessed to see whether there was a difference in spectral signature between control and ripened plots.

There were contradictory variations in the spectral response between experiments. Generally the flight date was too soon after ripener application for there to have been significant physiological changes to the canopy and cane samples from the plots did not indicate elevated sucrose levels. In one experiment comprising 20 plots, which covered 10 varieties ripened with Fusilade 6 and 14 weeks prior to the flight, the application of ripener was mirrored by a decrease in the reflectance of Band 4 (750nm) and an increase in reflectance of Band 1 (450nm). This confirms what is expected as Band 4 is related to canopy moisture, with less red radiation being reflected as a result of moisture in the canopy. In healthy canopy there is a strong absorbance by chlorophyll around the 400 to 450nm waveband. The increased reflectance of Band 1 on ripened cane was thus expected.

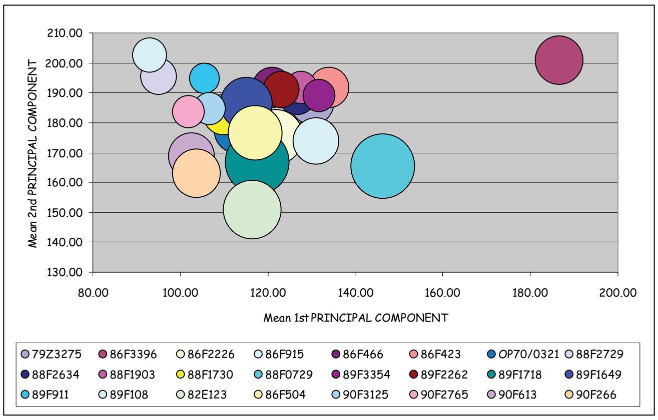

Figure 4. Bubble diagram of first and second principal component for 24 varieties (ARC, 2000a).

In another experiment investigating ripener application on an 11 month old field of N24 which was split into 5 plots, Ethrel and Fusilade was applied 5 and 8 weeks prior to the flight. Field samples from the plot ripened with Ethrel showed elevated sucrose levels but not from the Fusilade plot. The results of the DMSV analysis showed a clear increase in Band 4 (NIR) reflectance for the Ethrel ripened plot, in accordance with the results from the laboratory analysis of sucrose content.

e) Age of Sugarcane and Ground Cover

The purpose of this experiment was to assess whether DMSV could distinguish between age of cane and extent of ground cover. One field comprising 32 plots of two varieties (N28 and N30) and four ages (0,1,2, and 3 weeks) was sampled. Infield tiller counts showed a close relationship with age of cane. Reflectance in the 750nm waveband, Band 4, was significantly correlated with the number of tillers per hectare, and hence age of crop. The analyses showed a significant correlation between band B4 and both green leaf count and number of tillers per hectare. Figure 5a illustrates the variation in tillers per hectare with variety and age (in weeks) while Figure 5b illustrates the "signature" for each variety/age combination based on a principal component analysis of the plot reflectances.

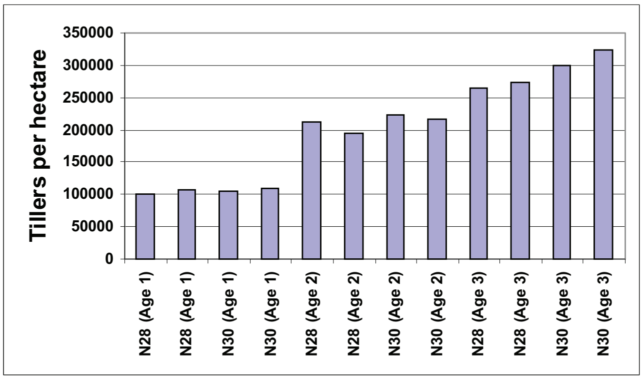

Figure 5a. Field readings of number of tillers per plot

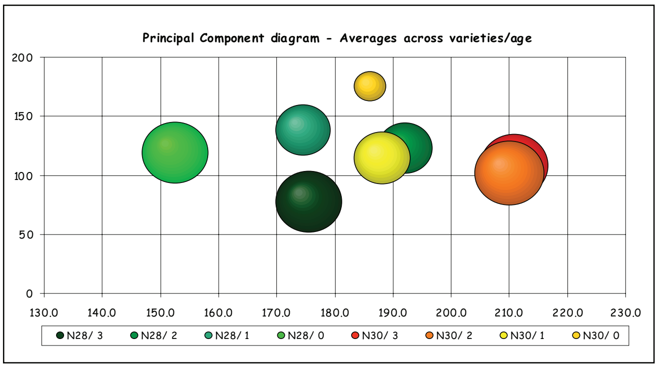

Figure 5b. Principal component bubble diagram of reflectance for plots with different variety and age (in weeks).

f) Fertilizer Application

The aim of this experiment was to assess whether DMSV could identify changes in canopy nutrition following different application rates of fertilizer to test plots. Leaf samples from the test plots were analysed in the laboratory with NIR to determine nutrient and chemical makeup of the leaves. No clear trend between topdress and control plots was evident from either the laboratory tests or the DMSV results. Drainage problems in some of the plots, evident on the image, confounded the analysis.

g) Yield Mapping

Two commercial sugarcane farms were also flown. Sugarcane yield estimates and actual yield measured at harvest were obtained for selected fields. It was hypothesised that there would be a correlation between yield and one of the vegetation indices from the DMSV image. The results showed that there was no significant correlation between either estimated or recorded yield (tc/ha) and median NDVI sampled for the field. It was nevertheless interesting to note that fields where yield was overestimated were generally those fields that had a low NDVI.

Discussion

The study was an initial investigation into the use of a digital multi-spectral video camera, mounted on a microlite, for assessment of sugarcane condition. The study showed promising results in distinguishing varieties and crop age (canopy cover) and identifying water stress and drainage problems. Broad scale commercial mapping of sugarcane variety would however require a comprehensive classification of the "spectral signature" of existing varieties under a range of situations (for example crop age). The study showed potential for mapping ripened cane although early signs of ripening, before identification with the human eye, does not appear feasible.

DMSV can be used for field mapping and area determination as an alternative to conventional photography. A ground resolution of 0,5m is possible which provides adequate accuracy. Careful consideration however needs to be given to ground resolution, depending on application. In this study a ground resolution coarser than 0,5m would, with hindsight, have been preferable to reduce the variability or "noise" in spectral response within plots.

The main benefit of the DMSV technology remains rapid acquisition of images of a vegetation index, which can be used for visual identification of anomalies, to allow timeous management intervention. The study has shown that identifying differences in canopy condition by eye from the image is relatively easy. Image processing software can be used to enhance these visual differences and map them. Identifying and quantifying the cause of changes in canopy condition from the image, in order to automate diagnosis of the problem and map it, does not however appear feasible.

There were numerous teething problems in data acquisition and camera equipment setup, which affected project results. For commercial service further development to improve reliability and quality control is required. There is also a need to justify the cost-benefit of operations by quantifying the decisions that would be taken following image acquisition and the benefits to be derived from them.

The ARC are currently involved in a development programme to expand expertise and resources in this area, upgrade logistic support, and improve data processing and analysis procedures. Other applications of airborne imagery being explored by them (ARC, 2000a) include:

- Estimation of the number of trees in a forest or orchard,
- Recognition and inventory of invasive species,
- Development of procedures to assess crop moisture stress for timely irrigation scheduling.
- Development of procedures for identification of pest and diseases damage.
- Soil mapping for farm management.
- Monitoring of soil salinisation.
- Identification of suitable spectral bands for mapping micro and macro nutrient deficiencies
- Monitoring soil erosion
- Mapping urban expansion.

This study focussed only on the four wavebands currently supported by the DMSV sensor. Other filters specific to some characteristic of sugarcane requiring monitoring could be targeted.

The commercial cost of operations described depends on the platform used (microlite or aeroplane) and ground resolution (0,5m to 3m). Costs also reduce as area surveyed increases. A preliminary cost indication is given below :

NOAA AVHRR Satellite

The National Oceanographic and Atmospheric Administration (NOAA) operates a series of satellites that orbit the earth at an altitude of 833km, and image a 2400km swath as they pass. The Advanced Very High Resolution Radiometer (AVHRR) sensor

Table 1. Approximate unit costs (R/ha) for DMSV data acquisition and processing.

Resolution	Microlite (R/ha)				Aeroplane (R/ha)			
	1000ha	5000ha	10000ha	>20000ha	1000ha	5000ha	10000ha	>20000ha
0,5m	16.5	10.5	9.5	9	30	19	17.5	16.5
1,0m	12	5.7	5.3	4.75	22	10.5	9.6	8.6
1,5m	10.5	4.5	3.7	3.5	19	8.5	7	6.5
2,0m	10	3.7	2.9	2.6	18	7	5.5	5
2,5m	9.6	3.3	2.5	2.2	18.5	6	4.5	4
3,0m	9.4	3.2	2.3	1.9	17	5.8	4.2	3.5

on board these satellites has a coarse ground resolution of 1,1km, but its particular strength is that it images any point at least once a day, cloud cover permitting.

Satellite data could offer a timeous and relatively cheap means to assess crop condition and yield. The relationship between NOAA AVHRR satellite data and sugarcane was investigated by SASEX through a contract research project undertaken by the ARC Institute for Soil, Climate and Water (ISCW) Geoinfromatics Division. A summary of the main findings is given below.

Methodology

The study focussed on nine target areas in three regions of the South African sugar industry as shown in Table 2 below.

NOAA AVHRR satellite data for the period 1988 to 1998 was extracted for each target area, which comprised a block of approximately 3,3km by 3,3km, dominated by sugarcane. The NOAA satellite has a very course ground resolution of 1,1km by 1,1km, this is however considered adequate for determining macro trends in crop condition. Ten-day maximum value composite maps were derived to cope with cloud cover and provide aggregate indices of spectral response for each target area over the study period (ARC, 2000b).

NOAA captures images in 5 channels, comprised of two infrared, one red and two thermal bands. These images were used to derive a standard vegetation index called the NDVI or Normalised Differential Vegetation Index, which gives an index of crop condition or the "greeness" of the crop. The NDVI gives a measure of the absorption of red light by plant chlorophyll and the reflection of infra-red radiation by water filled cells. The NDVI is computed from the near infrared (NIR) and red part of the electromagnetic spectrum as follows :

NDVI = (NIR - Red) / (NIR + Red)

The NDVI is a widely used vegetation index, which has been found to be correlated with the percentage of photosynthetically active radiation intercepted by the plant.

In the context of sugarcane yield estimation Lovick and Kirchner (1991) showed using Landsat TM data that moisture levels dominate the spectral signature of cane, masking long term stalk development trends. Noonan (1999) has more recently demonstrated how, using modern image processing techniques and vegetation indeces such as NDVI, Landsat TM was able to accurately predict sugarcane yield over two seasons (1998and1999) in two districts of Australia.

Historical records of sugarcane production were obtained for each mill and target farms in each study area (Table 2). The ten-day maximum NDVI was accumulated over periods representing the growth cycle of each harvest year crop. By integrating the value of the NDVI over a period of time one is integrating the condition or "greeness" of the crop over its growth cycle and assuming this accumulated condition will be correlated with overall production or yield of the crop. This approach has been successfully used for other crops but not tested for sugarcane, which has a different crop physiology (Gordon and Brink, 1995; Hobbs, 1995; Prince, 1990). Various periods for NDVI integration were investigated (ARC, 2000b). The resulting index of accumulated NDVI was compared with the observed Mill and Farm yields to see if they were correlated. A close correlation would imply that the NOAA satellite could be used operationally to improve on crop estimates.

Much project effort was focussed on extracting and processing the NOAA data before computing the NDVI index. Roderick, Smith and Cridland (1996) have shown the importance of atmospheric corrections, sensor calibration and the impacts of bi-directional reflectance when using NDVI derived from AVHRR data. Four different satellite and sensor platforms were used by NOAA over the study period and consideration had to be given to the calibration and radiometric correction of the data (ARC, 2000b).

Results

Trends in NDVI over target areas

Figure 6 gives the time series plot of NDVI for the target area Mhlati in Mpumalanga over the study period (January 1988 to

Table 2. Target areas to evaluate NOAA satellite data for crop yield assessment.

1. Rainfed North Coast Region

Target Area	Mill Served	Target Farms
Doornkop	Glendale	Sprintz, Mayfield, Mt Albert, Townlea
Shakaskraal	Gledhow	Holmdale
Darnall	Darnall	Bleakhouse, Fort Pearson, Williamson

2. Irrigated Mpumalanga Region

Target Area	Mill Served	Target Farms
Mhlati	Malelane	Mhlati
Tenbosch	Malelane/Komati	Tenbosch
Komatidraai	Malelane/Komati	Komatidraai

3. Rainfed Midlands South Region

Target Area	Mill Served	Target Farms
Burnside	Illovo/Eston	Crausaz
Roseleigh	Illovo/Eston	Roseleigh
Hayfields	Illovo/Eston	Dukes

December 1998). Each point plotted represents the median value of the NDVI for the 9 pixels comprising the 3,3km by 3,3km target area. The date given on the horizontal axis represents the year (2 digits), month (2 digits) and 10-day period in the month (1st, 2nd or 3rd). A three period (30-day) moving average line is plotted to illustrate the cyclic trend. Figure 7 gives the 60-day moving average plots for each target area in each region. A similar pattern with an approximate 12 month cycle is evident in all areas. While one would expect this pattern to be related to changing illumination conditions between seasons, the use of a normalised difference index (NDVI) compensates for changing illumination conditions. The variation shown is thus related primarily by the condition of the land cover in the target area, particularly the chlorophyl and moisture status of the crop (Lillesand and Kiefer, 1994).

Owing to the large (3,3 x 3,3km) scale of the target area, measured reflectance will be affected by factors other than the condition of the crop, including roads, grassland and other land uses present. Targeted areas were however selected such that sugarcane dominated the landscape. The focus of the study was to compare NDVI trends between years and see if they were correlated with yield trends. The extent of harvest and replant areas will also affect light reflectance and the recorded NDVI value. If one can assume the age profile of cane in a target area to be similar at the same stage each year, this should not affect interpretation of the NDVI trends.

Variations in the NDVI pattern are noticable both between target regions and between target areas within a region (Figure 7). An important factor is likely to be the prevailing crop condition or "greeness", as affected by drought, frost and other climatic influences. For example Figure 7 clearly shows lower values of NDVI over the drought period of 1992-1995. Examination of the NDVI plots also indicates that while trends within a region are similar much of the time, in certain periods the NDVI plot for a particular area deviates from the general trend.

Focus of the project was to accumulate the area under the NDVI curve, for each target area, over the crop growth cycle contributing to each year's harvested crop. The resulting accumulated NDVI was correlated with recorded sugarcane yield. This approach has been successfully tested for other crops such as maize (Maselli, Conese, Petkov and Gilbert (1992) and Gordon and Brink, (1995)) but not for sugarcane, which has a very different crop physiology.

Various periods over which to integrate the NDVI curve were investigated (ARC, 2000b). The method reported here is illustrated in Figure 8 for a 13 month period. The results presented are for a 13month period for all regions except the Midlands where results for both a 23month and 13month period of integration are presented (see Tables 3 and 4).

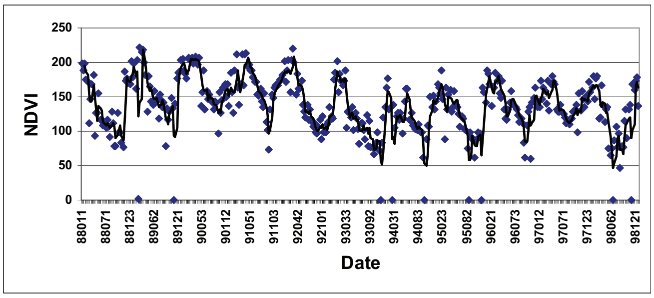

Figure 6. NDVI values and 30-day trendline for Mhlati (1988 – 1998).

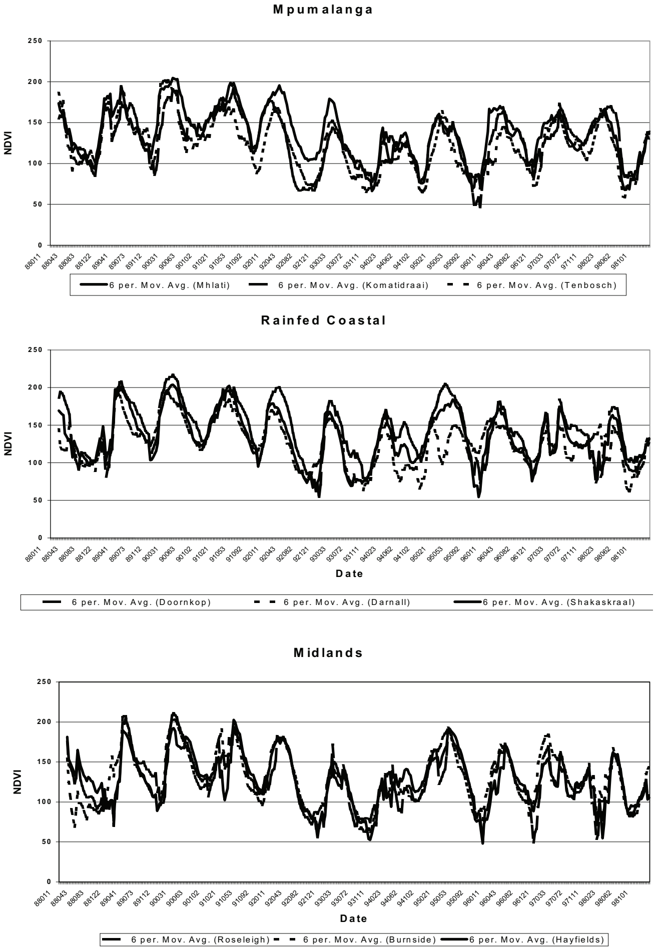

Figure 7. NDVI 60-day moving average for 3 target areas in each of three regions (Mpumalanga, Midlands and North Coast).

Correlation between NDVI and Mill Area Yield

Aggregate sugarcane yield data (tc/ha harvested) was obtained for the mills supplied by each of the target areas (See Table 2). A regression analysis was performed to compare accumulated NDVI with measured sugarcane yield. The results are given in Table 3.

Note : NDVI integration period for Rainfed coast and Mpumalanga areas 13 months. Midlands area NDVI integrated over 23months and 13months (in brackets).

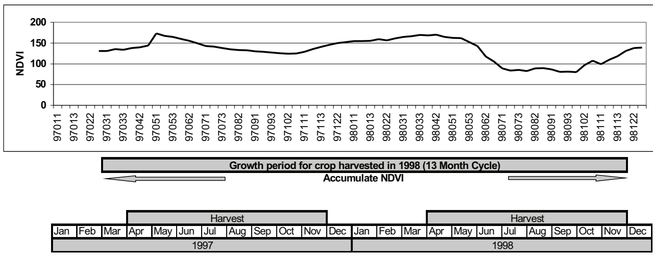

Figure 8. Illustration of method used to integrate the NDVI curve over the crop growth cycle for a particular harvest year (eg 1998). In this example for a 13-month crop NDVI is accumulated from March 1997 to November 1998.

Table 3 : Regression results – NDVI vs Sugarcane yield (Mill Data).

Target Area	Mill	Correlation	Standard Error of Estimate	Significance
Rainfed Coast				
Darnall	Darnall	.67	8.9	5%
Shakaskraal	Gledhow	.72	9.2	5%
Doornkop	Glendale	.57	4.5	NS
Mpumalanga				
Mhlati	Malelane	.75	13.1	2%
Tenbosch	Malelane	.84	10.5	1%
Komatidraai	Malelane	.81	11.6	1%
Midlands				
Hayfields	Illovo/Eston	.37 (.59)	15.4 (13.3)	NS (NS)
Roseleigh	Illovo/Eston	.30 (.49)	15.8 (14.4)	NS (NS)
Burnside	Illovo/Eston	.42 (.61)	15.0 (13.6)	NS (10%)

Note : NDVI integration period for Rainfed coast and Mpumalanga areas 13 months. Midlands area NDVI integrated over 23months and 13months (in brackets).

Table 3 shows that correlations for Mpumalanga sites are highly significant, however the standard error of the yield estimate (10 to 13 tc/ha) shows relatively low precision. Figure 9 illustrates the relationship between Malelane Mill yield and NDVI for the Komatidraai target area. Years of low NDVI clearly coincide with years of low yield. Non significant correlations were obtained for the Midlands target areas. Correlations improve for the shorter (13month) period of NDVI integration. Owing to relocation of the mill, Illovo Mill yield data was used up to 93/94 and Eston Mill yield data from 94/95. The Midlands target areas are not fully representative of the Illovo supply area. This contributed to the poor correlations. Trends in NDVI for the three target areas and Eston Mill yield data from 94/95 show a clear relationship, although there are too few points for statistical significance to be inferred.

Table 4. Regression results – NDVI vs Sugarcane yield (Farm Data).

Target Area	Correlation	Standard Error of Estimate	Significance
Rainfed Coast			
Darnall	.81	10.3	1%
Shakaskraal	.54	7.8	NS
Doornkop	.33	4.3	NS
Mpumalanga			
Mhlati	.45	10.2	NS
Tenbosch	.94	8.9	1%
Komatidraai	.51	26.8	NS
Midlands			
Hayfields	.57 (.79)	20.9 (15.4)	NS (2%)
Roseleigh	.52 (.73)	10.1 (8.1)	NS (5%)
Burnside	.81 (.79)	6.3 (6.6)	1% (2%)

Note : NDVI integration period for Rainfed coast and Mpumalanga areas 13 months. Midlands area NDVI integrated over 23months and 13months (in brackets).

The results of this analysis have shown a relationship between NDVI, as measured with NOAA NDVI, and regional sugarcane yield. On a regional scale, monitoring the condition of the canopy, could provide valuable information on the status of the crop, especially in the Mpumalanga areas.

Correlation between NDVI and Farm Yield

A similar analysis to that described above was performed using aggregate farm yield data for farms located in each of the target areas (See Table 2). The results of the regression analysis comparing accumulated NDVI against measured farm sugarcane yield are given in Table 4.

Note : NDVI integration period for Rainfed coast and Mpumalanga areas 13 months. Midlands area NDVI integrated over 23months and 13months (in brackets).

Table 4 indicates that the correlation at farm level is generally much worse than that at mill level, although significant correlations are found for 3 target areas, one in each region. Figure 10 indicates the relationship between NDVI and yield recorded for the three farms falling in the Darnall target area.

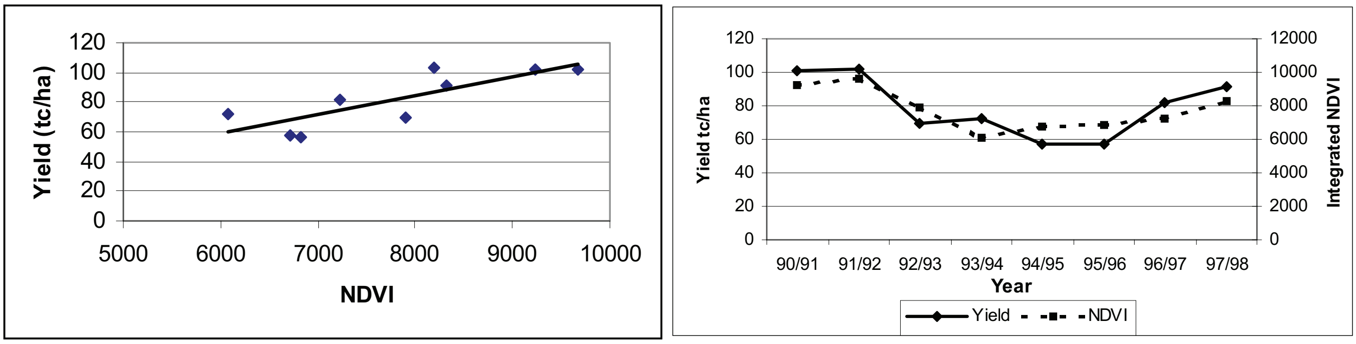

Figure 9. Scatter plot of sugarcane yield (Malelane Mill : 1989 – 1998) vs NDVI (Komatidraai site) and time series plot of NDVI and yield.

Discussion

This research has shown some interesting patterns in NDVI as measured by the NOAA AVHRR sensor. Variations in NDVI plots for each target area are related to changing condition of the sugarcane landcover in response to management practices (eg harvesting, planting and ripening) and condition of the crop, particularly the chlorophyll and moisture status of the crop.

The canopy condition of sugarcane, in terms of its moisture and chlorophyl status, as measured by NDVI, is not the only factor determining sugarcane yield. Nevertheless this research has shown that regional sugarcane yield for the Malelane and to a lesser extent Darnall, Gledhow and Eston Mill supply areas, correlates with NDVI as, measured by NOAA AVHRR at sample areas within their supply region. Poor correlations were obtained when comparing Glendale and Illovo yields with NDVI.

The target areas for extraction of NDVI data (3,3km x 3,3km or 1089ha in extent), only represent a small portion of the supply area for each mill, which is typically some 30 000ha in extent. It is likely that by extracting NDVI data for a larger portion of the supply area, better relationships with aggregate mill production would be attained.

Correlation of farm yield records with NDVI was generally worse than that for mill yield records, despite the fact that farms were located in the target area of the NDVI image. This is probably due to the fact that farm management decisions, such as carry over cane, have a significant impact on yields, which were not represented in the the NDVI data. Nevertheless significant correlations between farm yield and NDVI were obtained in one of the three target areas of each region. Furthermore the target area of each satellite image generally extended well beyond the boundary of the selected farm(s). The NDVI would thus have been influenced by areas falling outside the farm. When using satellite data for farm scale yield estimation a satellite with a smaller spatial resolution (eg SPOT or Landsat TM) would be advantageous.

This study has been a preliminary investigation and has shown there to be potential for using remote sensing to assist in regional yield estimation. The use of other vegetation indeces, in conjunction with NDVI, could also assist in generating more accurate results. It should also be noted that the NOAA-AVHRR data sets used in this study were not fully calibrated which would have provided more reliable results. This must be addressed in further studies off this nature. Although the resolution of NOAA AVHRR is very coarse (1,1km x 1,1km) it is considered an appropriate and cost effective source of NDVI data for regional yield assessment.

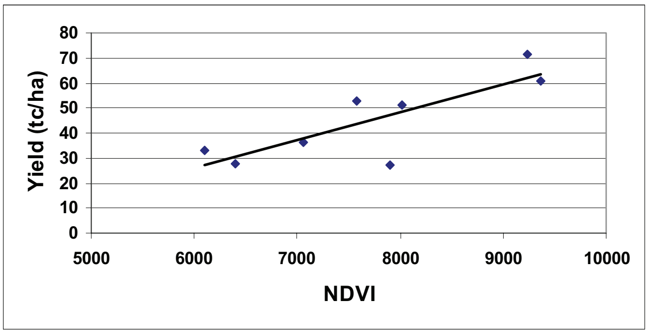

Figure 10 : Scatter plot of sugarcane yield vs NDVI (1989-1998) for Darnall target area (Farms : Bleakhouse, Fort Pearson and Williamson).

Conclusions

This study has looked at remote sensing for sugarcane monitoring and yield estimation. An airborne Digital Multispectral Video Camera (DMSV) showed promising results in distinguishing varieties and crop age (canopy cover) and identifying water stress and drainage problems. The study showed potential for mapping ripened cane although early signs of ripening, before identification with the human eye, does not appear feasible.

The main benefit of the DMSV technology remains rapid acquisition of images of a vegetation index, which can be used for visual identification of anomalies, to allow timeous management intervention. The study has shown that identifying differences in canopy condition by eye from the image is relatively easy. Identifying and quantifying the cause of changes in canopy condition from the image, using image processing techniques, in order to automate diagnosis of the problem and map it, does not appear feasible at this stage. This study focussed only on the four wavebands currently supported by the DMSV sensor. Other filters specific to some characteristic of sugarcane requiring monitoring could provide improved results.

This research has shown interesting patterns in NDVI as measured by the NOAA AVHRR sensor over the period 1988 to 1998. Significant correlations between average sugarcane yield over a mill area and NDVI were obtained for five of the nine sample areas. The target areas for extraction of NDVI data only represented a small portion of the supply area for each mill and it is likely that by extracting NDVI data for a larger portion of the supply area, better relationships with aggregate mill production would be attained.

Correlation of farm yield records with NDVI was generally worse than that for mill yield records. Farm management decisions, such as carry over cane, have a significant impact on yields, which were not represented in the NDVI data. Furthermore the target area of each satellite image generally extended well beyond the boundary of the selected farm(s). When using satellite data for farm scale yield estimation a satellite with a smaller spatial resolution (eg SPOT or Landsat TM) would be advantageous.

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